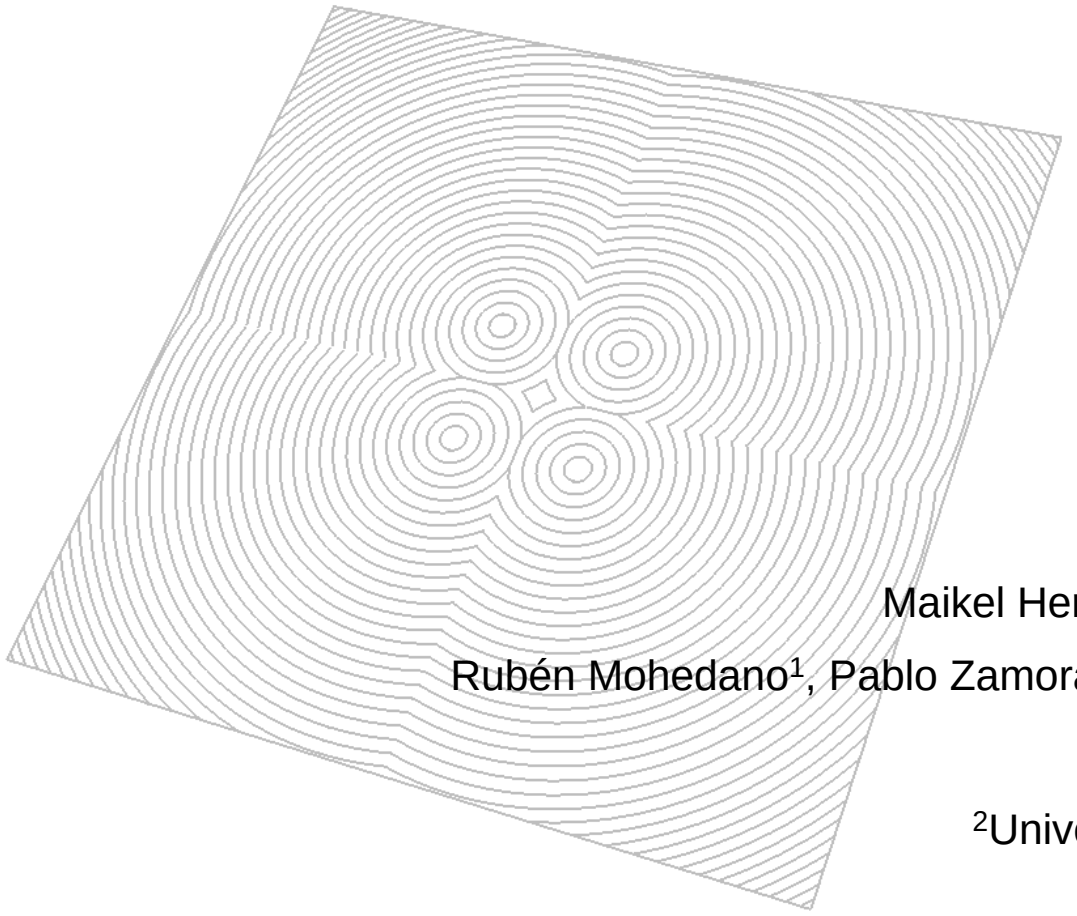
FK concentrator outdoor measurements

San Diego, August 2013



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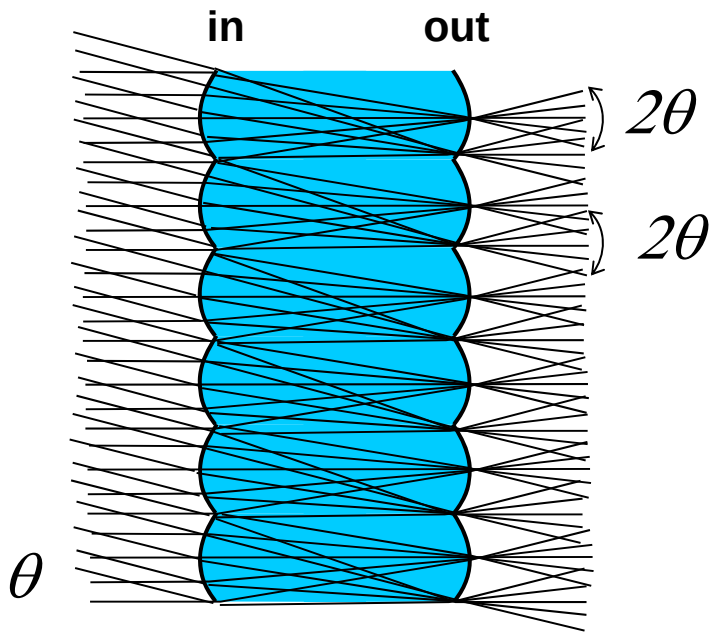
Outline

- FK concentrator overview
- Optimal spectral design
- Latest measurement results
- Conclusions

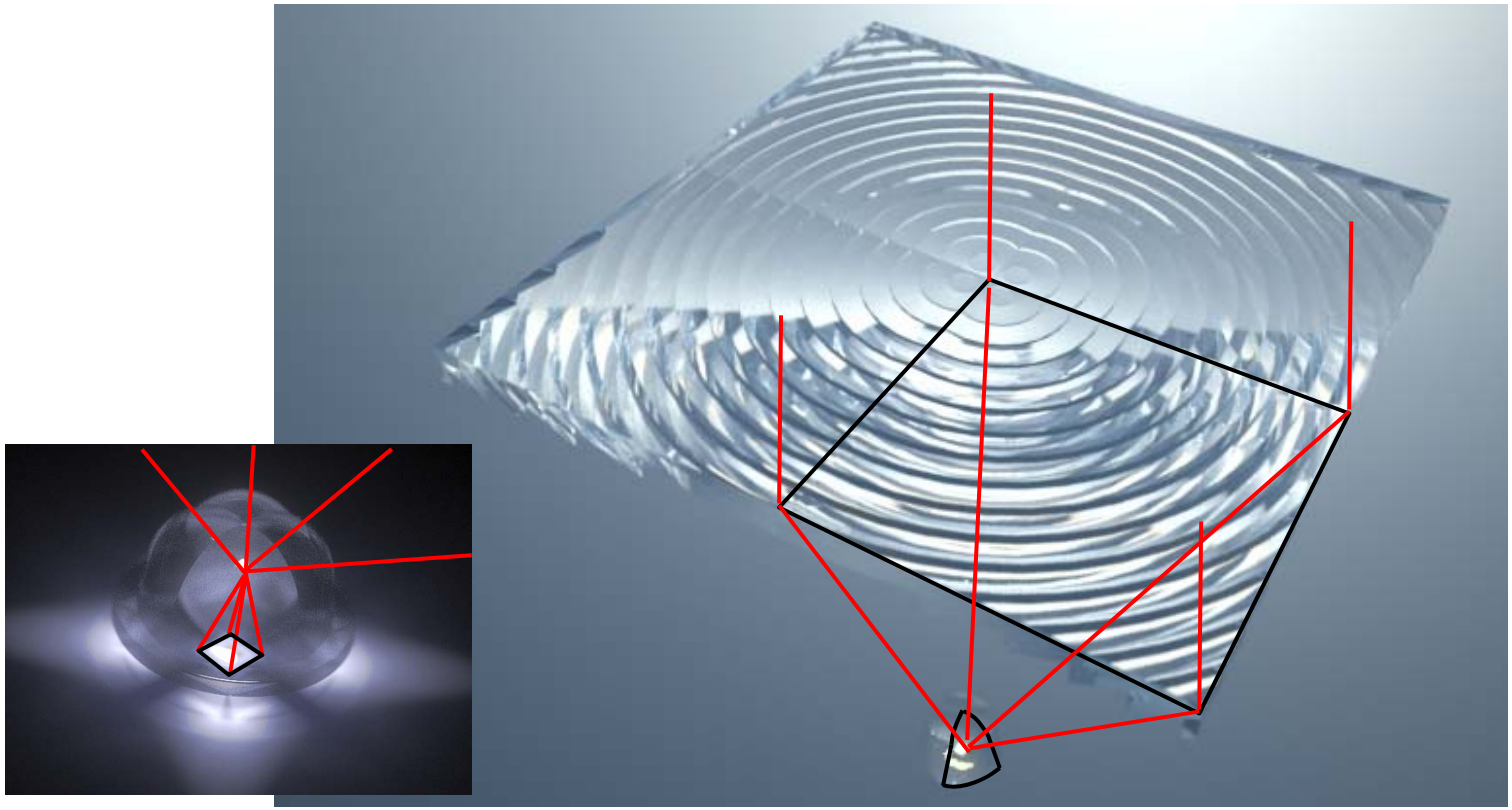
Köhler integration

- Two-stages design where input/output stage forms image of a preferred object point onto a point of the output/input stage
- Canonical example: two identical lenses imaging a point source at infinite (plane wavefronts) onto each other



Köhler integration in the FK

- Advanced concentrator using LPI-proprietary 4-channel Köhler homogenization
- POE folds image the sun onto SOE folds, which in turn image the POE folds onto the square solar cell



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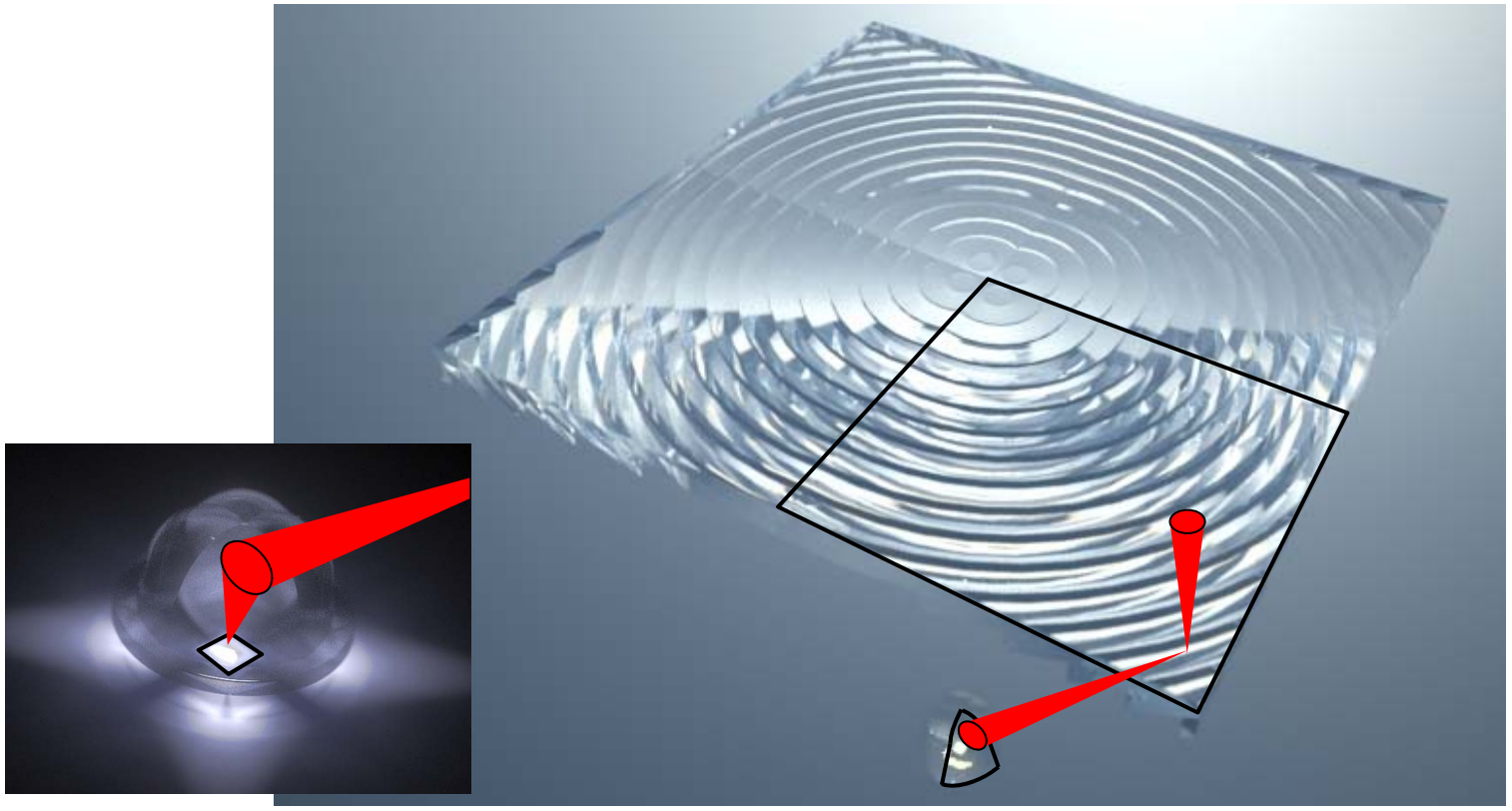

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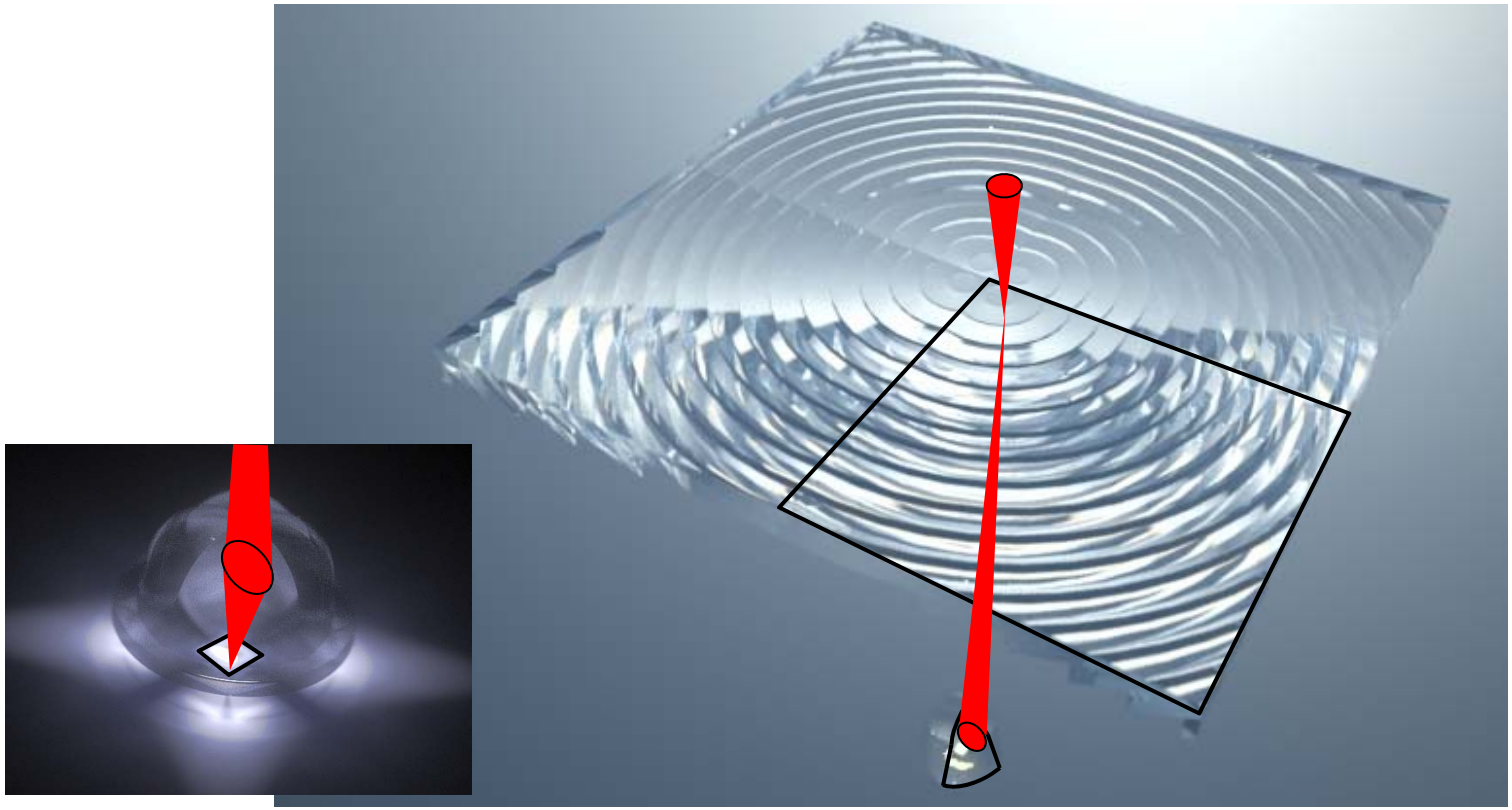
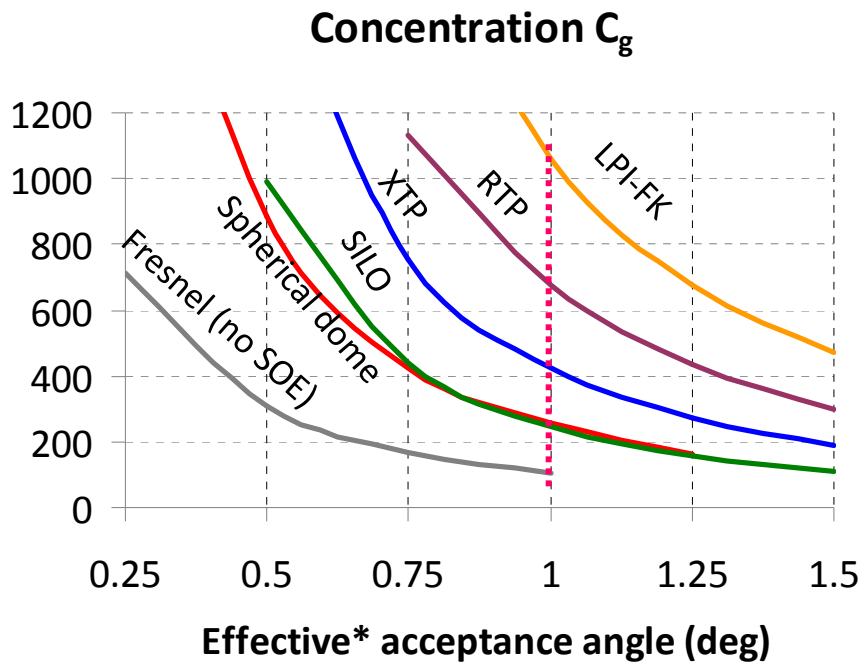


FK compared to other Fresnel concentrators

•Higher Concentration-acceptance product (CAP): for a fixed minimum acceptance angle, the FK can concentrate more

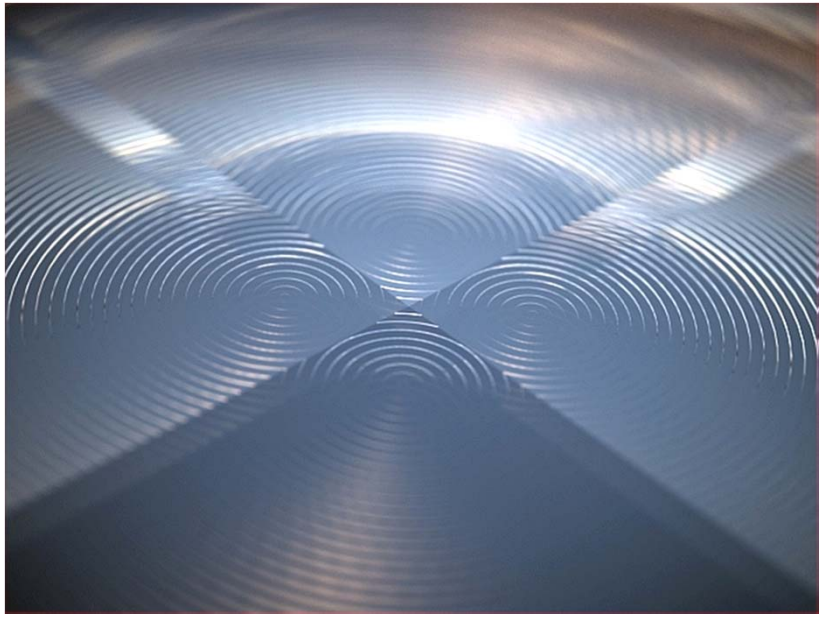


*includes sun finite size, optical losses, and MJ cell photocurrent

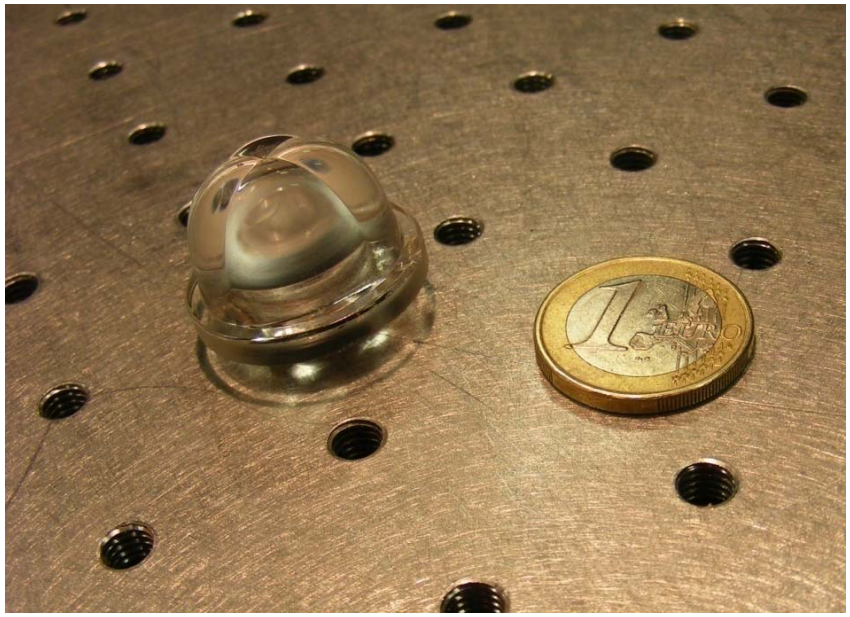
FK features

- Optical depth reduced with respect to other Fresnel systems (0.85<f#<1.2)

Fresnel lens (POE)

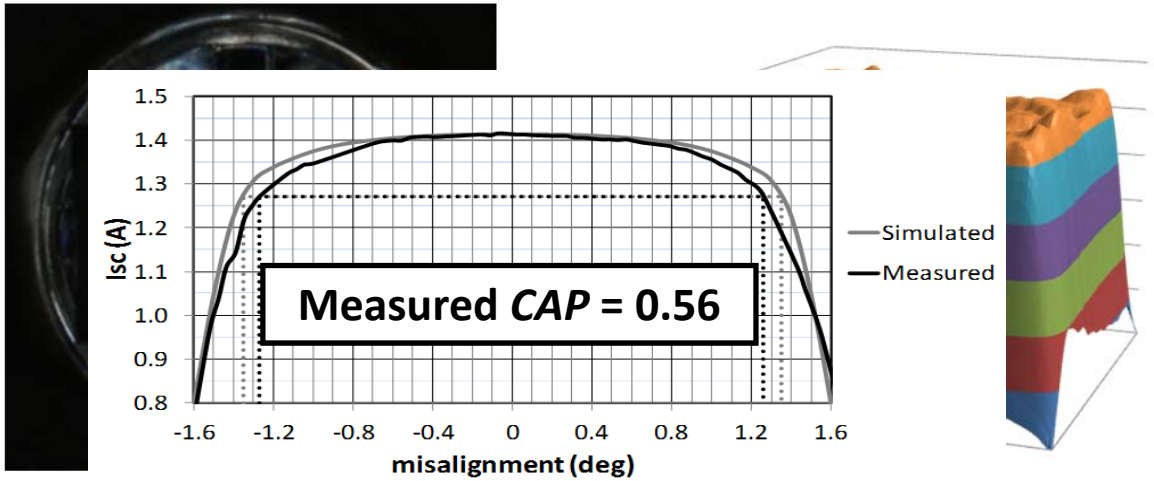


Freeform secondary lens (SOE)



FK features

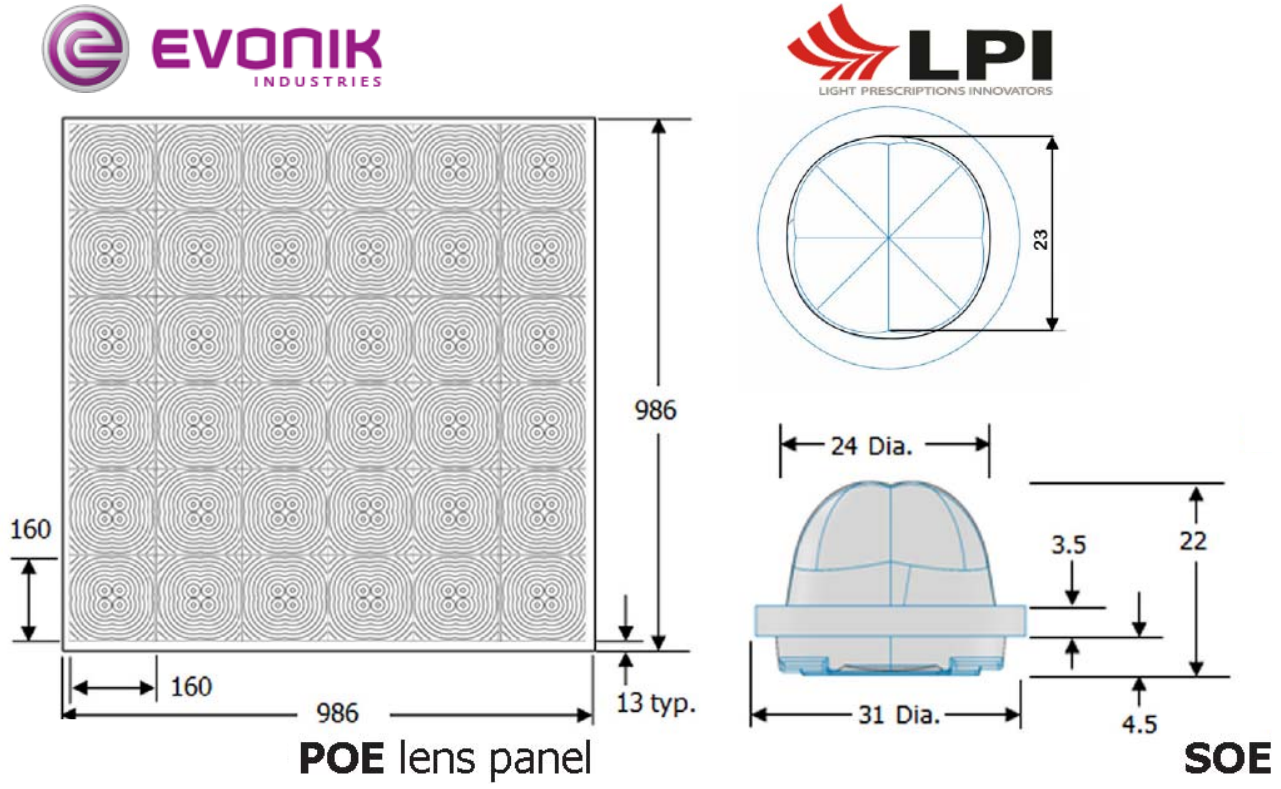
- High concentration
- High optical efficiency
- High spatial and spectral irradiance uniformity on the cell (high cell efficiency and long-term reliability)
- High acceptance angle (preserves high efficiency at array level)
- Low cos



P. Zamora, et. al. "Experimental characterization of Fresnel-Köhler concentrators," J. Photon. Energy. 2(1), 021806 (Oct 16, 2012).

Ventana™ Optical Train:

A complete off-the-shelf optics solution by Evonik and LPI using acrylic POE



Outline

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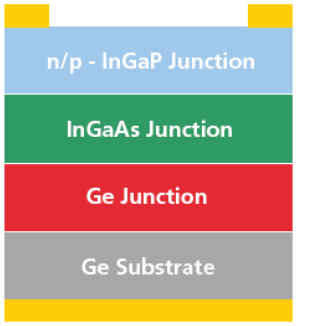
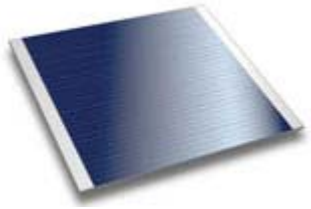
- **Optimal spectral design**
- Latest measurement results
- Conclusions

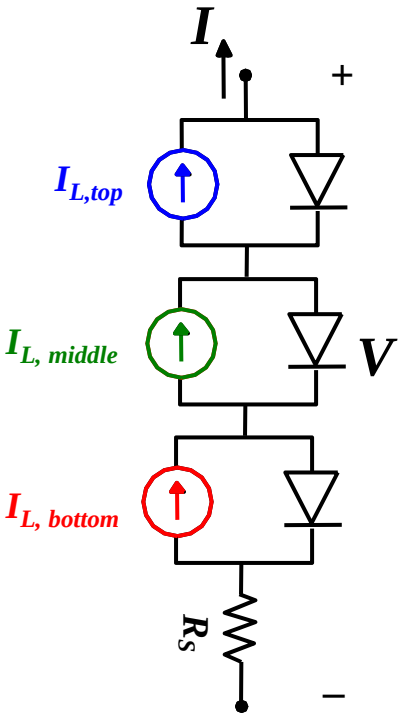
Spectral transmission issue

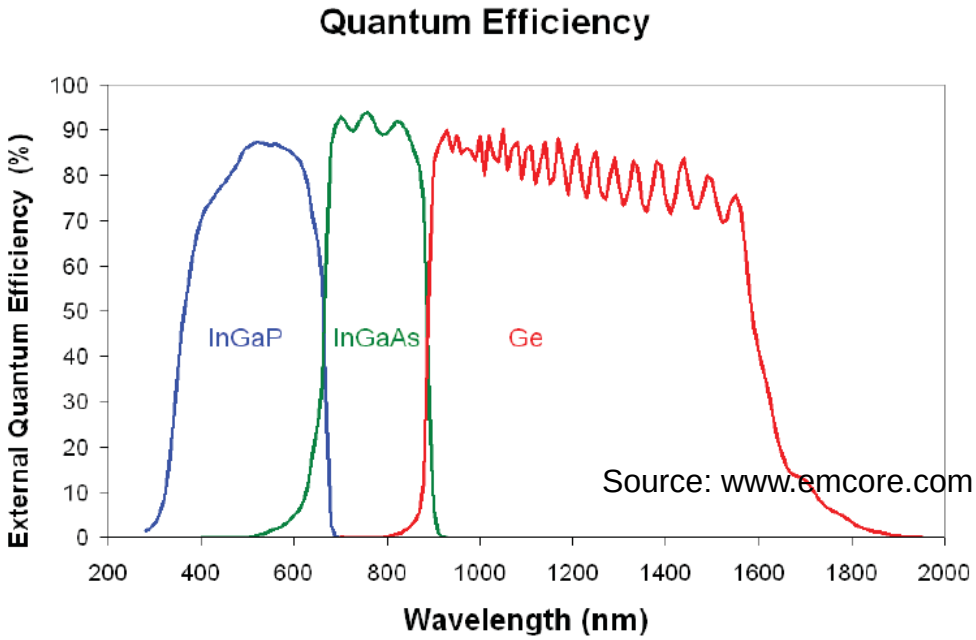
- Solar cell junctions are series-connected, the goal is keeping balanced photocurrents for bottom, middle and top sub-cells



Cell Structure Diagram
(Tunnel diodes not shown)

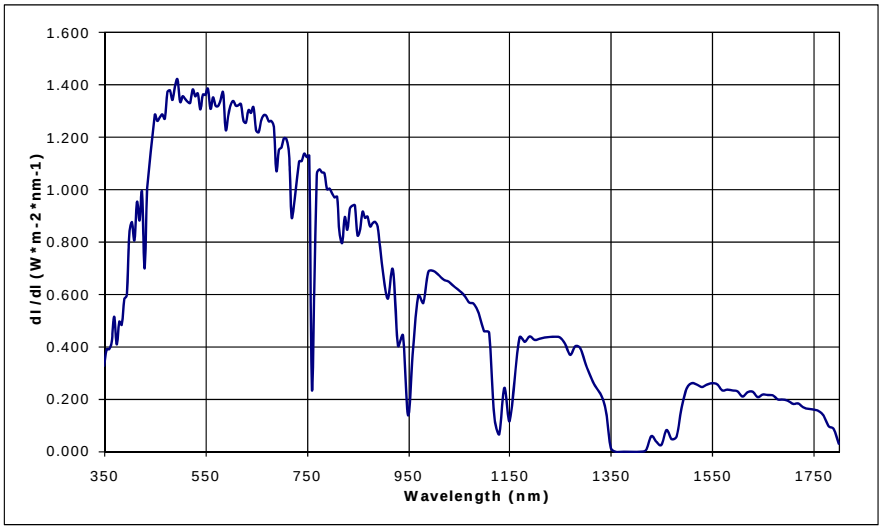




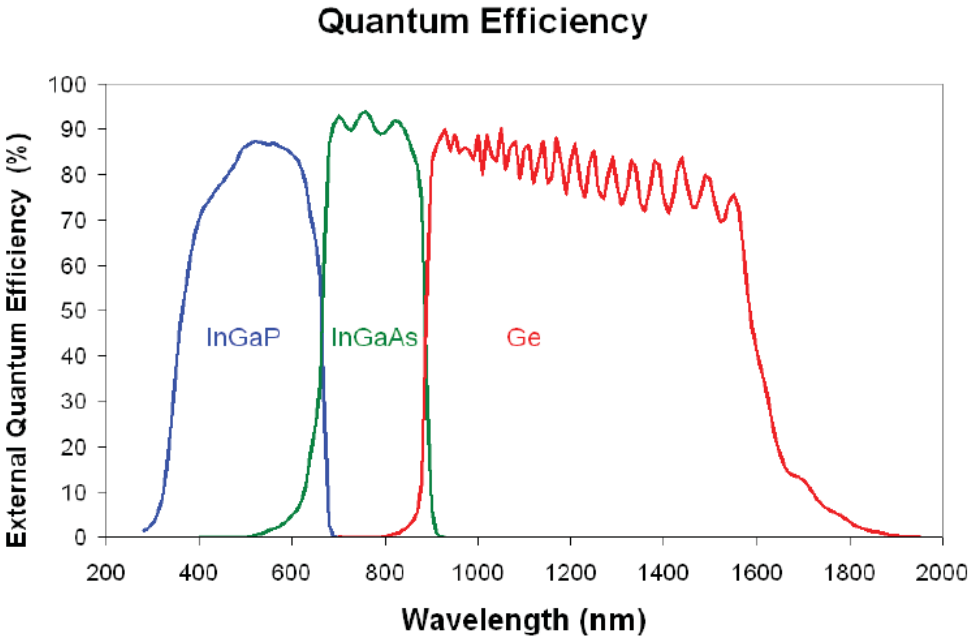


Spectral transmission issue

- Solar cell junctions are series-connected, the goal is keeping balanced photocurrents for bottom, middle and top sub-cells
- Best performance is achieved when the concentrator considers spectral characteristics of both sunlight and solar cell



AM 1.5 spectrum containing a power density of 900W/m^2

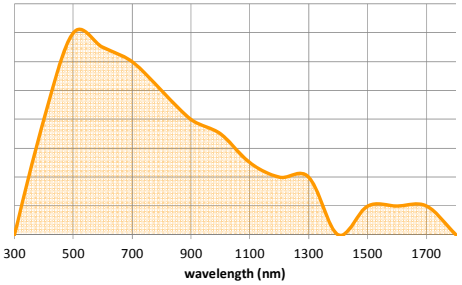


3J solar cell EQEs (Source: www.emcore.com)

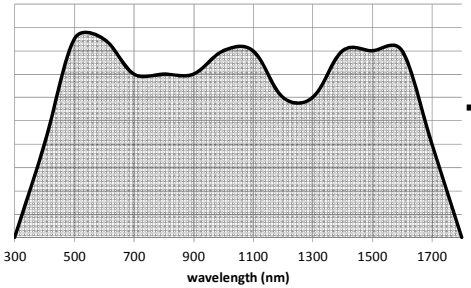
Spectral transmission issue

- A careful optical design and good choice of optical materials maximize energy production throughout the year

Solar spectrum S(λ)



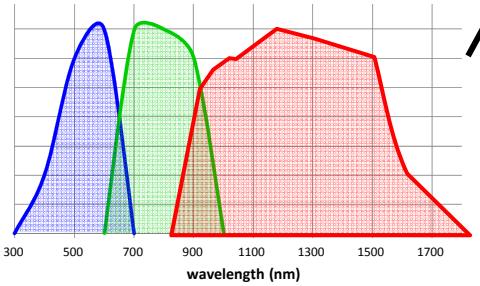
Concentrator optical transmission T(λ)



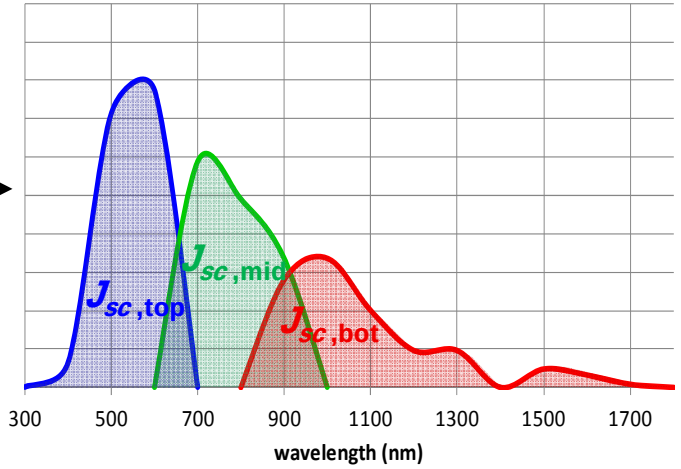
$EQE_{top}(\lambda)$

$EQE_{mid}(\lambda)$

$EQE_{bot}(\lambda)$

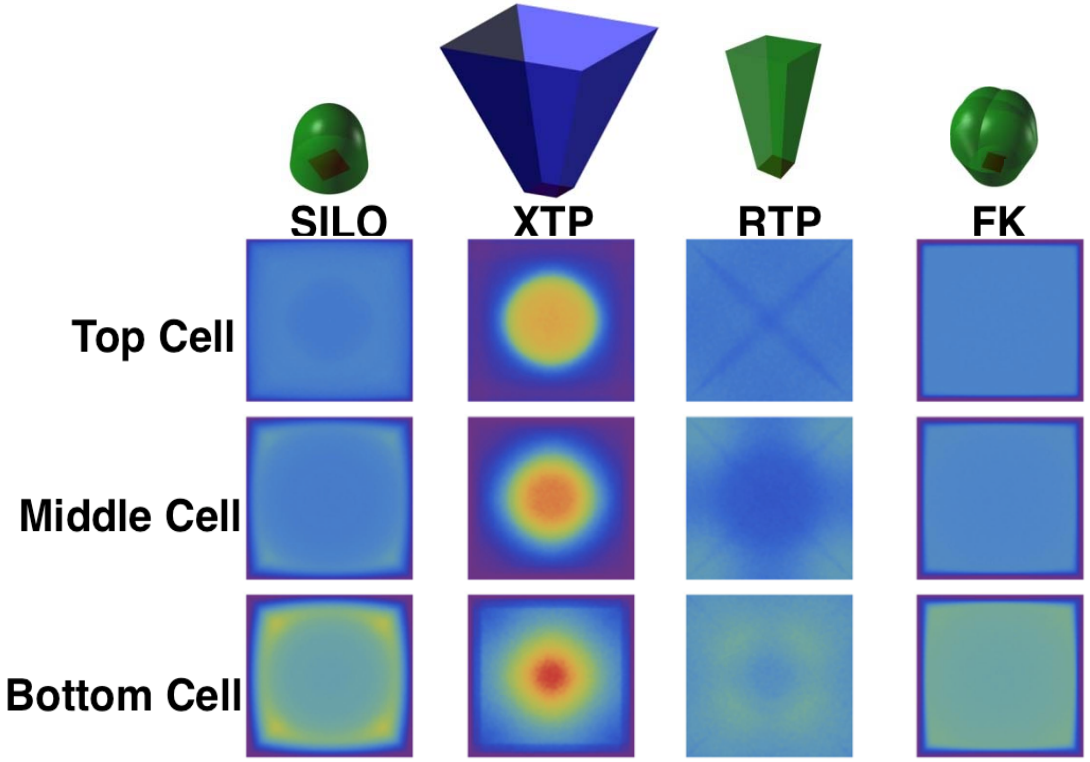


$$J_{sc,k} = \int S(\lambda)T(\lambda)EQE_k(\lambda)d\lambda$$

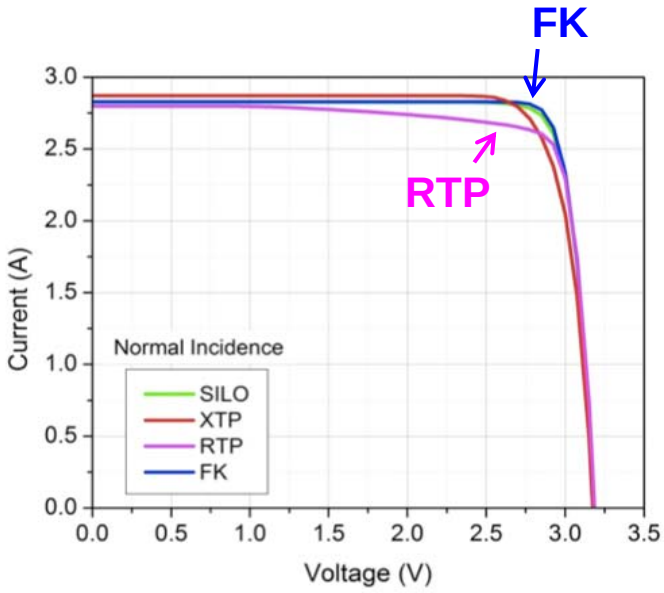


$$I_{sc} = \min\{I_{sc,top}, I_{sc,mid}, I_{sc,bot}\}$$

Spectral irradiance issue modelled



Tracker angle = 0º



P. Espinet-González et al., "Triple-junction solar cell performance under Fresnel-based concentrators taking into account chromatic aberration and off-axis operation", CPV-8 Proceeding, Toledo, Spain (2012).

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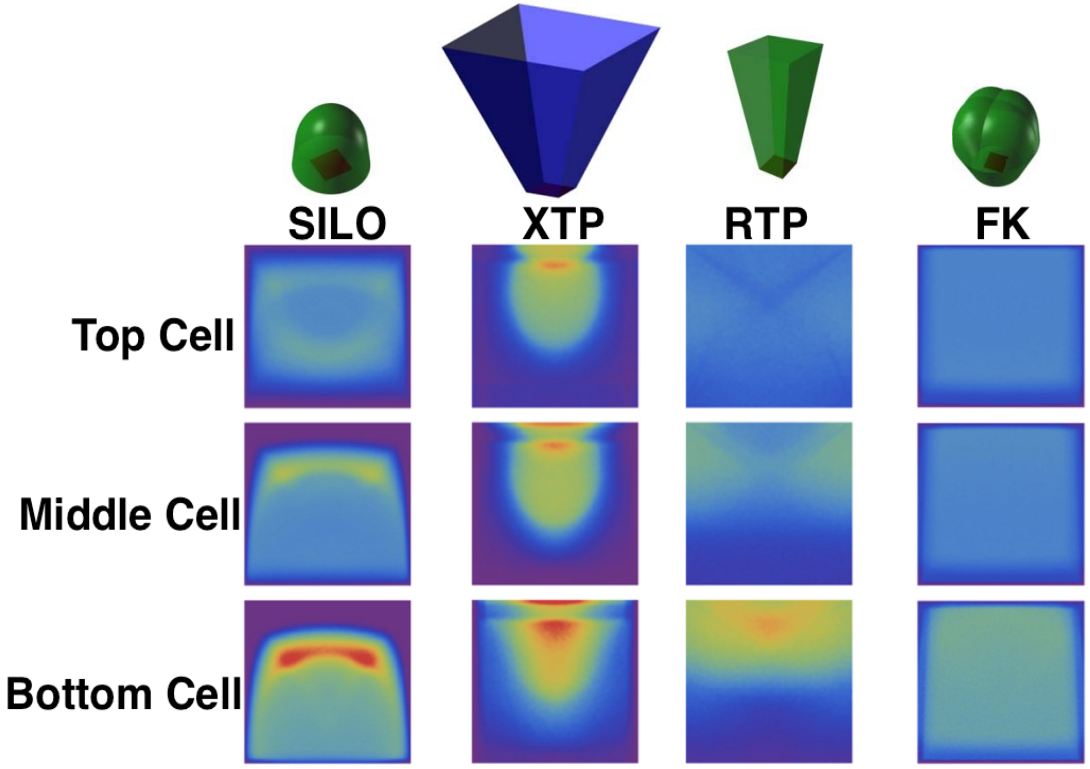
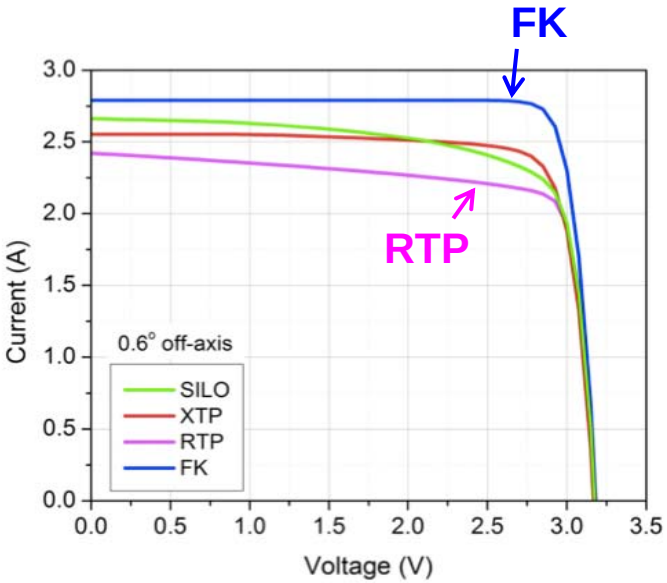


Tracker angle = 0.6º



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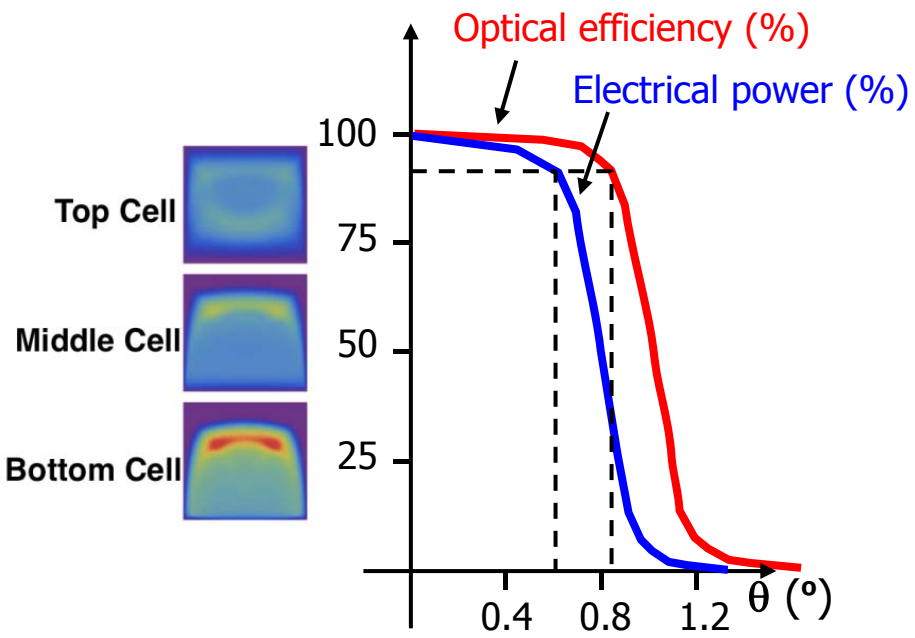
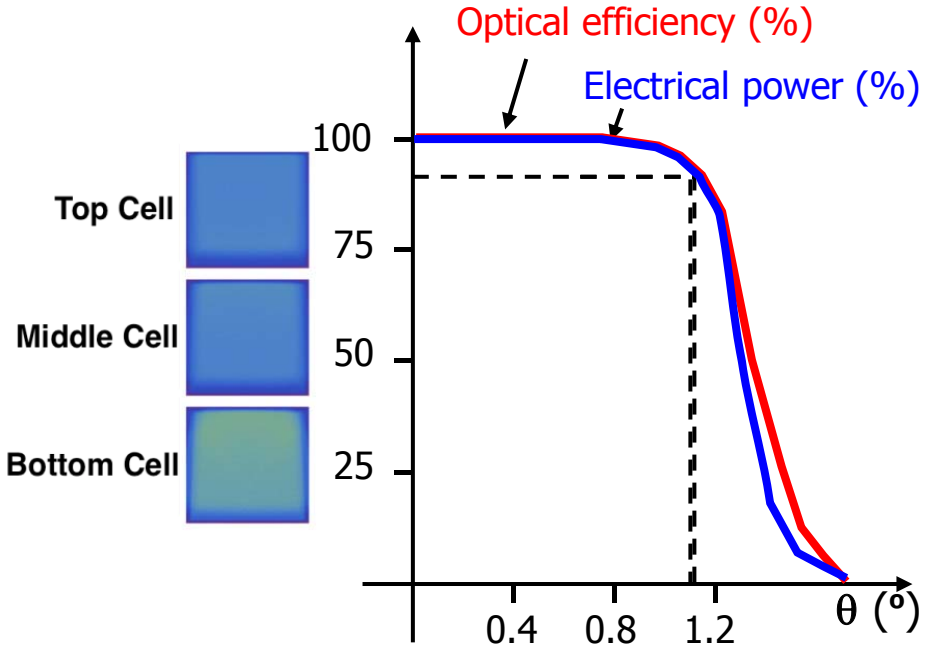
Spectral irradiance issue modelled

Silo



FK



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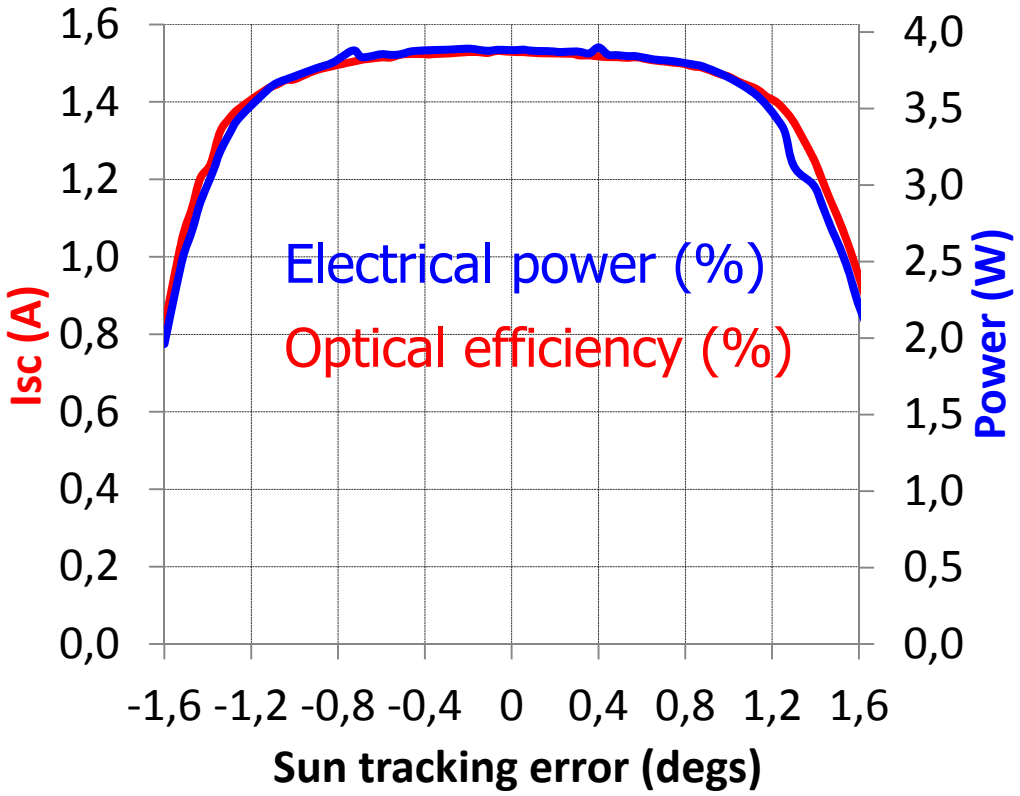
Spectral irradiance issue measured

- Measurements confirm the models



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